PG&E Introduction

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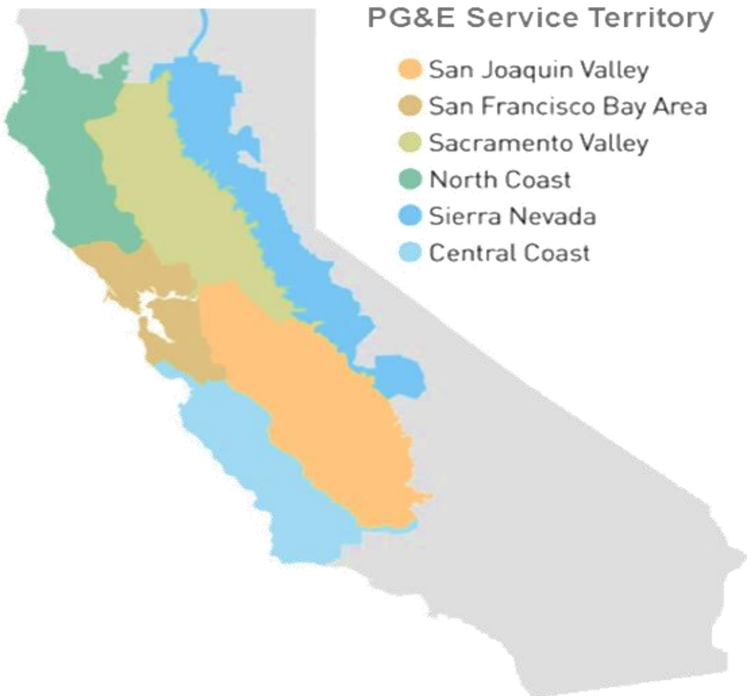
Pacific Gas and Electric Company®

PG&E at a Glance



Key Highlights

Employees	~24,000
Californians served	~16M
Revenue (2016)	~$17.6B
Net income (2016)	~$1.4B
Miles of electric lines	~160,000
Miles of natural gas pipelines	~50,000
MW utility-owned generation	~7,700
GWh electricity generated and procured	~68,500
Carbon-free and renewable energy delivered	~70%

EPIC Areas of Focus

EPIC Project Categories

Renewables and Distributed Energy Resources Integration

Grid Modernization and Optimization

Customer Focused Products and Services Enablement

Foundational Strategies & Technologies

Strategic Areas of Focus

- Enable DER growth and leverage both utility and customer owned DERs as a grid resource
- Demonstrate strategies and technologies to increase renewable resources on the grid
- Enable further engagement with internal/external stakeholders (CAISO, aggregators, etc.)

- Demonstrate strategies and technologies to optimize utilization of existing assets (e.g., by deferring need for replacement or upgrades)
- Further advancement of new processes and technology for T&D
- Increase effectiveness of asset monitoring / asset health

- Enable customer choice through new products and services
- Advance grid/grid edge capabilities
- Demonstrate technologies to increase EV and Energy Storage adoption

- Advance smart grid architecture, cybersecurity, telecommunications
- Enhance and apply tools to better prepare and respond to natural disasters
- Enhance safety infrastructure and physical security (e.g. utilizing robotics and drones)

EPIC Project Examples (Completed Projects' Reports @ www.pge.com/EPIC)

- 1.01 Energy Storage for Market Operations Utilized battery energy storage to demonstrate automation communications and CAISO participation

- 2.02 DERMS (in progress) Demonstrate new technology to monitor and control DERs to manage system constraints and evaluate potential value that flexible DERs can provide the grid

- 1.08 System Tool for Asset Risk (STAR) Demonstrated software that will calculate risk scores for transmission and distribution assets to be leveraged for developing asset strategies, planning activities and ad hoc analysis

- 1.09C Distributed Series Reactors Demonstrated DSRs on a transmission line. These devices are designed to increase line impedance, reducing line flow and redirecting that flow to parallel facilities.

- 1.21 Automatic identification of PV Leveraged smart meter analytics to develop an internal algorithm which will help PG&E identify PV systems that may not be registered with PG&E, helping us ensure safety and reliability.

- 1.24 Smart AC Load Reduction Deployed a sample of data logging devices on HVAC direct load control to gain insights on distribution feeder level performance of these installations (DR for Distribution Optimization)

- 1.09A Close Proximity Switching Demonstrated a portable remote controlled switch operator tool for sub surface Load Break Oil Rotary switches to improve public and employee safety

- 2.26 Customer and Distribution Automation Devices (in progress) Demonstrate physical and application interfaces to permit customer and third party devices to connect to the AMI networks

EPIC 3 Key Demonstration Areas

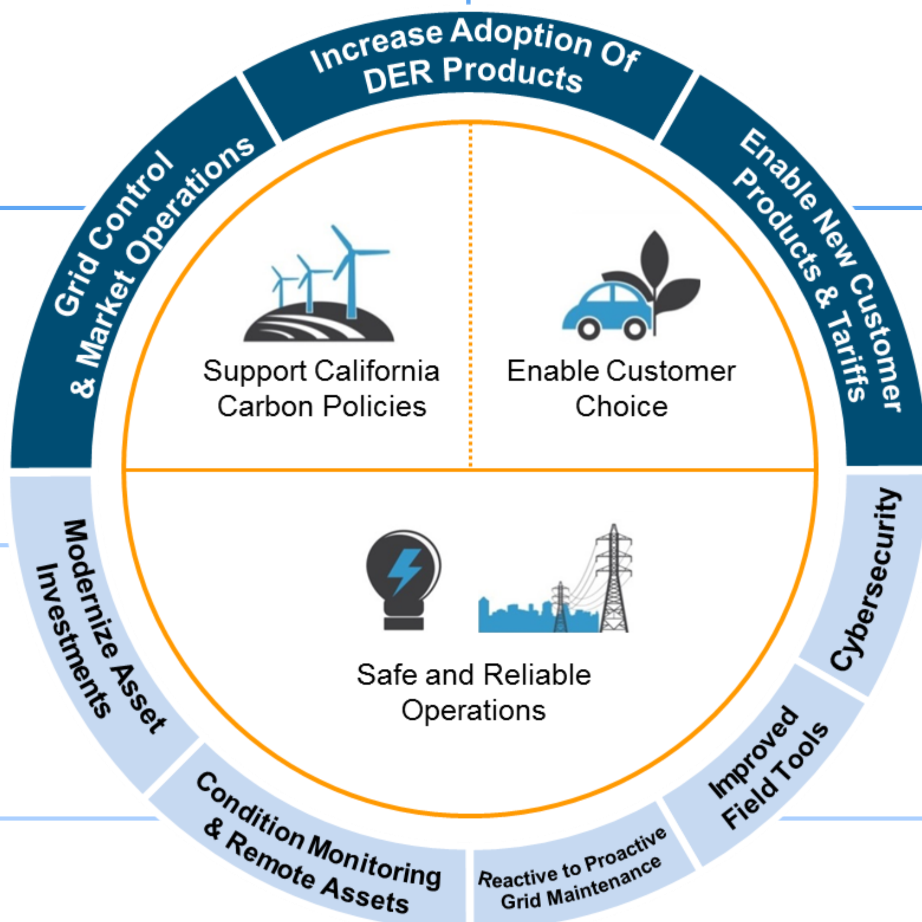
Enhance program targeting and combinations of DER technologies to enable easier **IDER / IDSM adoption** (e.g. EV w/ Storage, BTM Resource Optimization, Community Energy Resilience)

Increase adoption of **EV and Storage**

Expand operational capabilities (DERMS / ADMS) to **optimize the grid** through the use of DERs

Leverage transactive technologies to test **DSO grid capabilities and new DER Market Operations**

Enable more **dynamic and DER-oriented rates**, including valuation of DER grid services at a granular level to enable improved understanding of DER location based impacts / future potential tariffs



Improve **understanding of DER grid impacts**, location specific protection settings

Improve **protections against bad actor access** in critical facilities (e.g. rogue wireless access points, cyber-physical coordinated security)

Leverage sensor technology to improve **active monitoring of Grid Assets**

Leverage augmented reality, “SIRI”-type functions, and other associated field workforce tools to **improve field access to real-time information**

Move maintenance / outage mitigation from **reactive to proactive** leveraging advanced data analytics approaches

Presenters

EPIC 2.19 – Enable Distributed Demand-Side Strategies & Technologies

Morgan Metcalf

EPIC 1.02 – Energy Storage for Distribution Operations

Mike Della Penna

EPIC 2.19 – Enable Distributed Demand-Side Strategies & Technologies

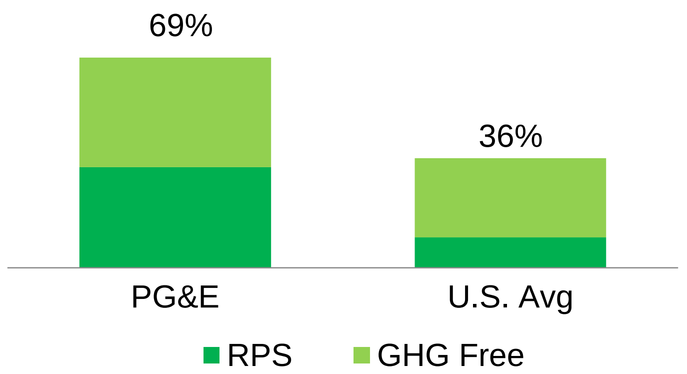
Morgan Metcalf

Agenda & Objectives

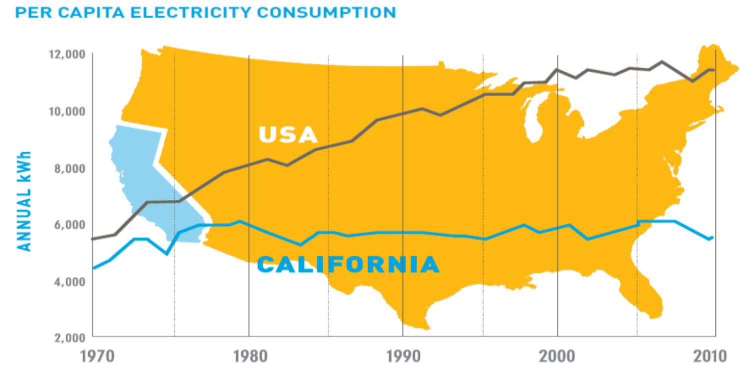
- California Policy landscape and the demand for BTM technology
- Overview of PG&E’s Grid of Things Technical Demonstration Projects
- Discussion of Technical Demonstration Projects Framework & Scoping
- Findings & Key Takeaways

California and PG&E
Lead Nation in Clean Energy Development

Nearly 2x More Carbon Free and Renewable Energy Than The U.S. Average in 2016



Shaping California Model for Energy Efficiency

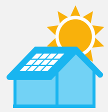


*Source: US Energy Information Administration

PG&E Customers Lead the Nation in Clean Technology Adoption

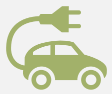
>280,000 Solar Customers

Ranked #1 with ~25% of all U.S. rooftop solar



> 100,000 Electric Vehicles

Ranked #1 with ~20% of all U.S. vehicles

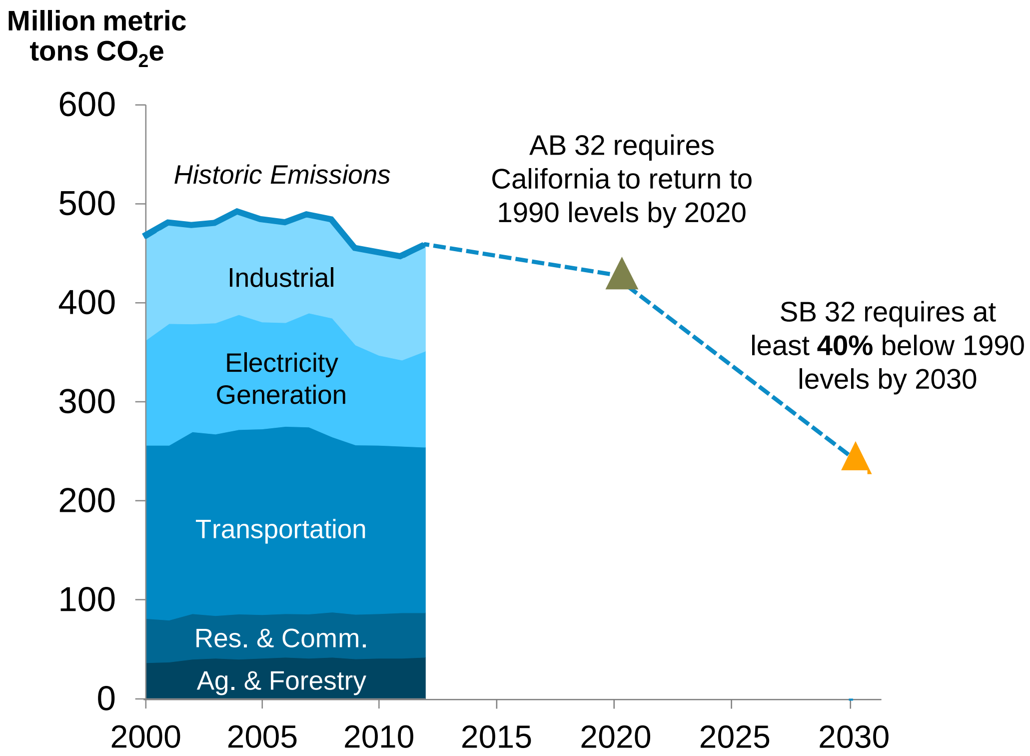


~800 GWh/yr of Efficiency Savings

Ranked #2 among U.S. utilities

Looking Ahead: 2030

California Greenhouse Gas Reduction Goals and Historic Emissions*



California is Targeting:

50%

renewables by 2030

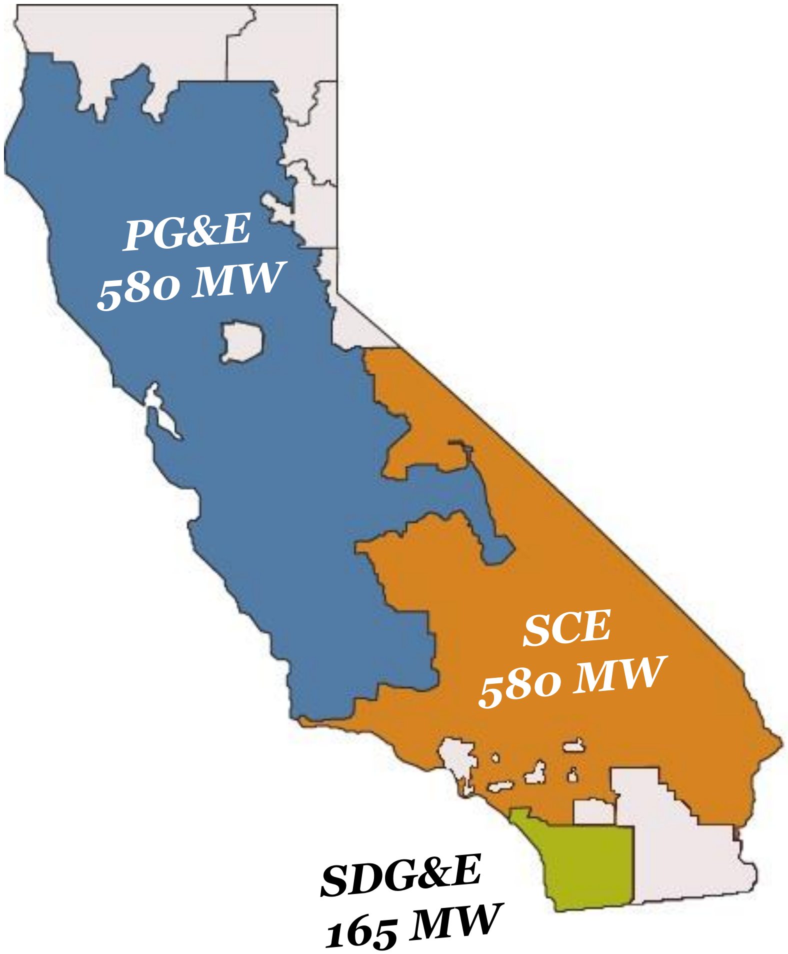
2X

energy efficiency in existing buildings by 2030

1.5M

electric vehicles by 2025

California Energy Storage Mandate

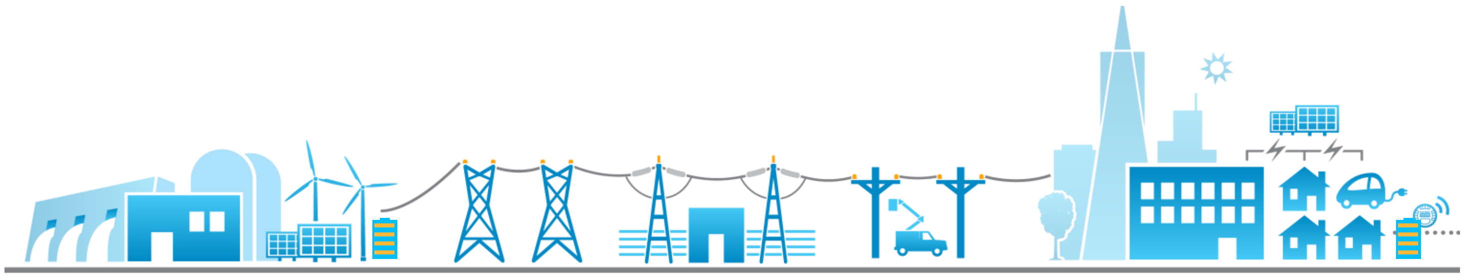


Contracts must be signed by 2020, and projects must be operational by 2024

Includes Front-of-the-Meter and Behind-the-Meter facilities

Excludes Pumped Hydro facilities >50MW

Storage Provides Market, Grid and Customer Value



	Market	Grid	Customer
Storage Services/ Value Drivers	• Intermittent generation • Excess generation • Price arbitrage	• Capital investment deferral • Enhanced reliability	• Customer cost savings, primarily on demand charge
Storage Technologies	Small Scale ↑ **Batteries** **Flywheels** **Compressed Air** **Pumped Hydro** ↓ Large Scale	**Batteries** **Flywheels**	**Batteries**

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Overview of San Jose DER “Sandbox”

Collaborating with 3rd party aggregators to engage customers and deploy a “fleet” of Behind-the-Meter (BTM) storage and PV with Smart Inverters to be controlled by Distributed Energy Resource Management System (DERMS) to provide Distribution Services

Residential BTM PV + Storage w/ Smart Inverter Control

- 124 kW PV
- 66 kW, 4 hr
- 27 customers

Vendor 1

Commercial Aggregated BTM Storage

- 360 kW, 2 hr
- 3 Commercial &Industrial customers

Vendor 2

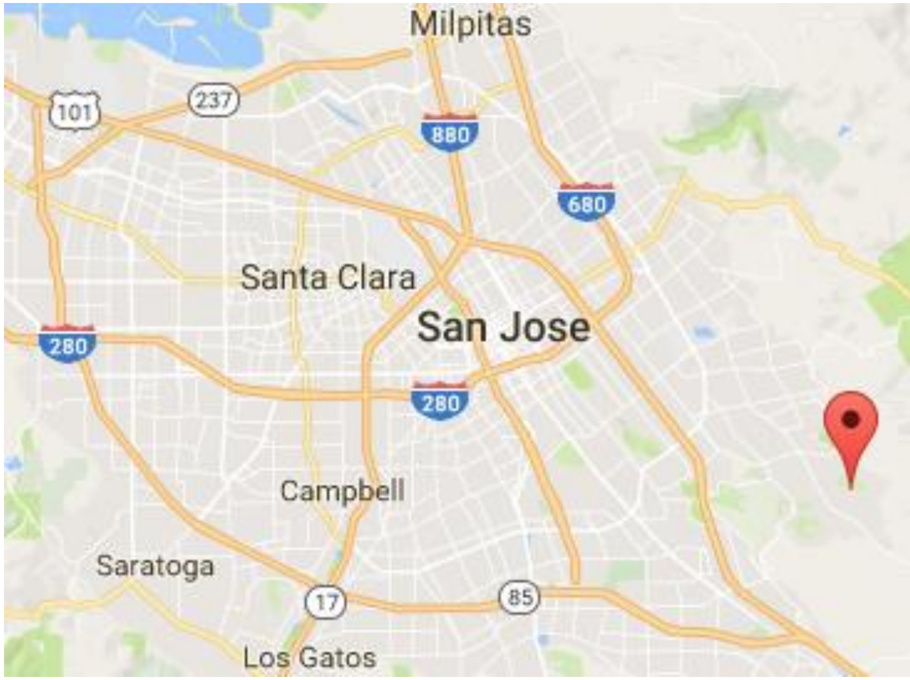
Utility Scale Yerba Buena Battery

- 4MW, 7 hr battery
- PG&E-owned, customer-sited
- Wholesale resource

EPIC 2.19 – Enable Distributed Demand-Side Strategies & Technologies

Overview:

- Technical Demonstration project to test both residential and commercial aggregated storage solutions.
- Demonstrate if aggregated customer-sited utility controlled BTM energy storage resources can be reliably and cost-effectively used:
  - To reduce peak loading or absorb distributed generation
  - As a non-wires approach to address capacity constraints as compared with other technologies used by the utility for the same purpose, such as replacing transformers and/or reconductoring



	# Sites	# Batteries	kW/ 4hr	kW/ 2hr
1. Residential Total	20	28	44.8	64.8
1a.Single Battery Home	*12*	*12*	*19.2*	*38.4*
1b. Double Battery Home	*8*	*16*	*25.6*	*26.4*
2. Commercial Total	2	8	120	240
Total	**22**	**36**	**164.8**	**304.8**

Project Objective, Reasons and Value

Objective — **Demonstrate distributed demand-side technologies and approaches**

- Demonstrate effectiveness of aggregated customer-sited BTM energy storage systems to reduce peak load or absorb PV generation on the distribution system
- Demonstrate reliable communications with BTM energy storage resources with real time visualization and control
- Evaluate ability of BTM energy storage solutions to simultaneously provide service to utility and customer
- Evaluate BTM energy storage meter measurement accuracy

Reasons — **Precursor to the fulfillment of Assembly Bills AB and Proceedings**

- AB 2514 and AB 2868, which require local, publicly-owned electric utilities to procure viable and cost-effective energy storage systems.
- Support Distribution Resources Plan R.14-08-013 proceeding, evaluating aggregated BTM customer energy storage as a non-wires alternative to address capacity constraints as part of the Integrated Distribution Planning Process.

Value — **Help guide long-term BTM energy storage vision**

- Reliability improvement utilizing storage as an additional grid resource or backup power
- Opportunities for customers to lower energy costs and help utilities defer upgrades which provides additional savings
- Storage integrated with photovoltaics can provide additional opportunities for renewable resources

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Use Case Testing Demonstration

Use Case 1 – Net Load Management

- Evaluate if aggregated Behind-the-Meter Energy Storage Systems can be reliably used to reduce peak load or store excess generation, per utility request (e.g., scheduled to fully charge from 10 AM to 4 PM, and discharge from 4 PM to 8 PM)

Use Case 2 - Reliable and Prompt Response

- Evaluate Behind-the-Meter Energy Storage Systems operational responsiveness and latency of dispatched commands

Use Case 3 - Provide Service to Utility and Customer

- Explore the opportunity for Energy Storage Systems to simultaneously providing grid services (e.g., reduce distribution line loading) in addition to reducing customer peak demand charges

Use Case 4 - Meter Accuracy

- Evaluate the accuracy of metering values provided by the Energy Storage Systems aggregators

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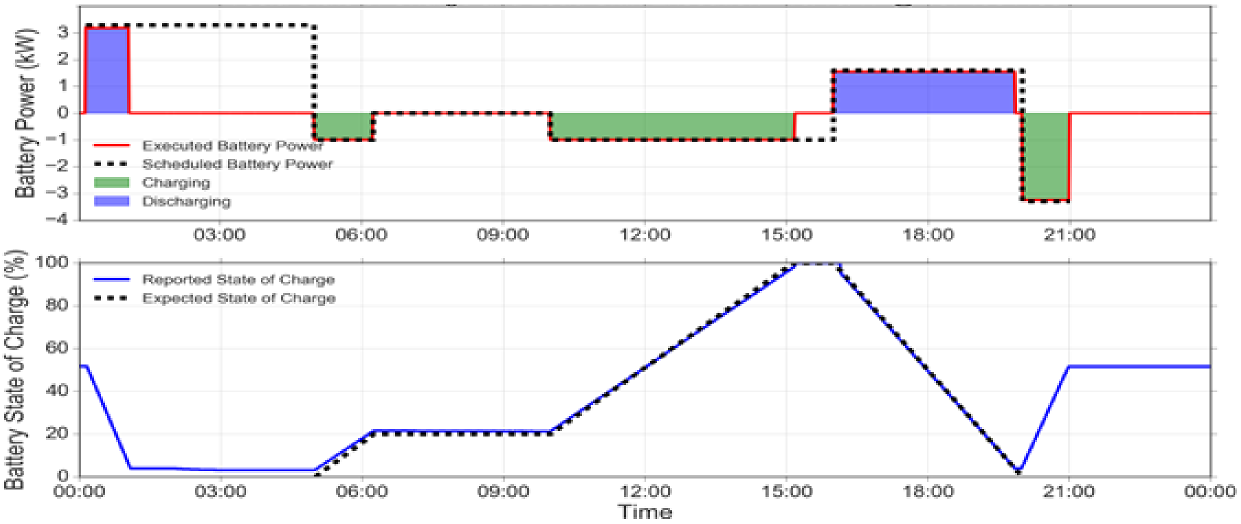
Technical Results – Key Accomplishments

Inverter kVA Limits

Energy Storage System achieved rated output. Commercial Energy Storage System is capable of operating at rated nameplate capacity while providing both active and reactive power.

Residential Behind-the-Meter Battery Power and State of Charge



Residential Behind -the-Meter Battery Power and State of Charge Test Setpoints

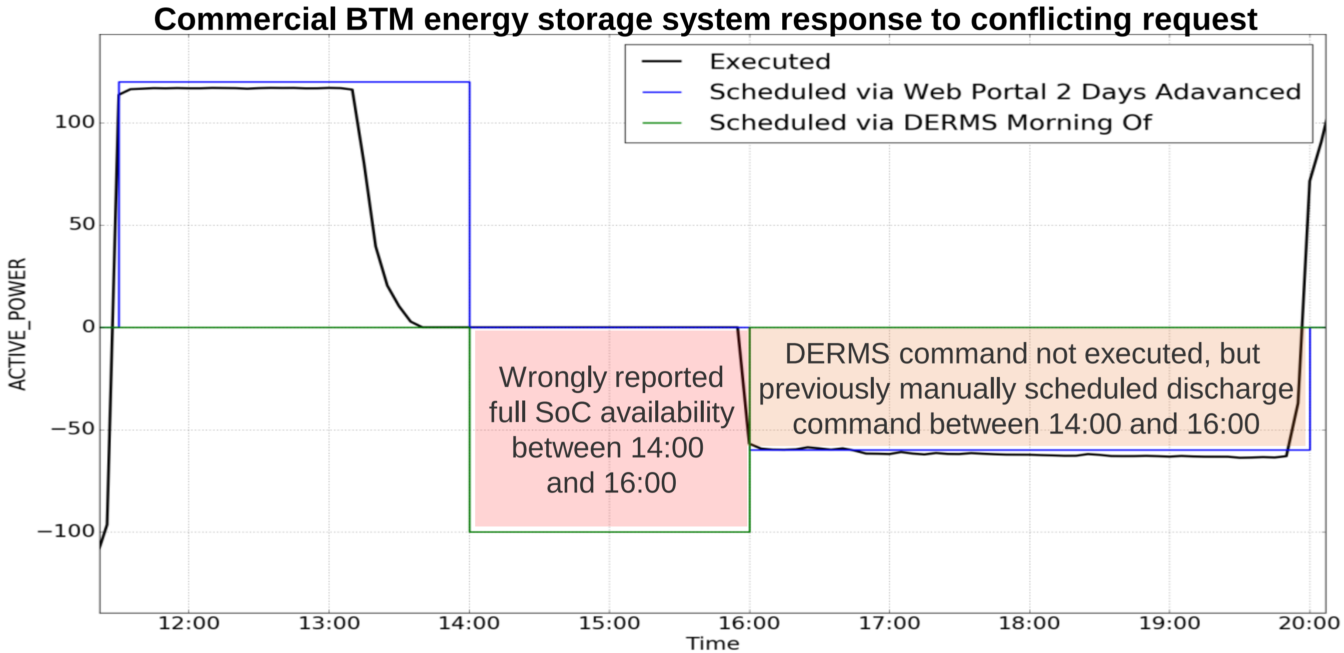
Start Time	End Time	Real Power Direction	Real Power Setpoint
00:10	05:00	Discharge	3.3 kW
05:00	06:15	Charge	-1 kW
10:00	16:00	Charge	-1 kW
16:00	20:00	Discharge	1.6 kW
20:00	21:00	Charge	-3.3 kW

State of Charge

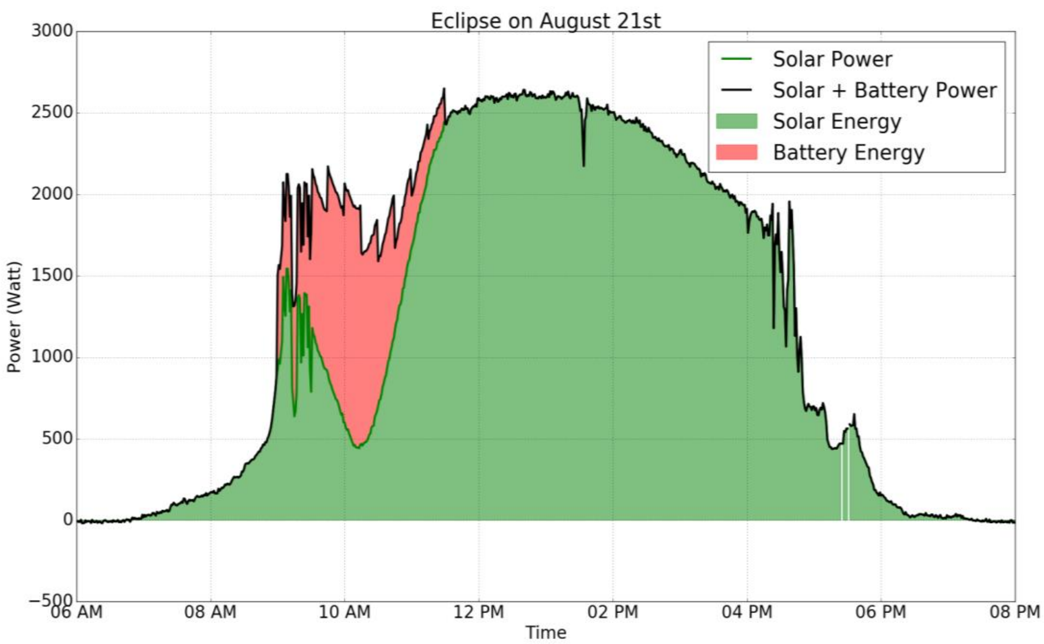
Commercial and residential ESS successfully followed scheduled charge and discharge commands.

Technical Results – Key Accomplishments (Cont.)

- **Load Shift**
  Commercial and residential ESS successfully reduced net load as requested (with few exceptions).
- **Flexibility Forecast**
  Both commercial and residential battery management systems reported inaccurate flexibility forecast. On conflicting request to discharge inaccurately reported flexibility, residential ESS executed while the commercial ESS did not execute the conflicting request.
- **Metering Validation**
  Residential inverter lab tests accurately measured power - within 1% in most cases. Commercial inverter field trial test results showed accurate measurements on average, but inaccurate individual ESS power measurements (up to 20% error).



Battery and Solar Working Together



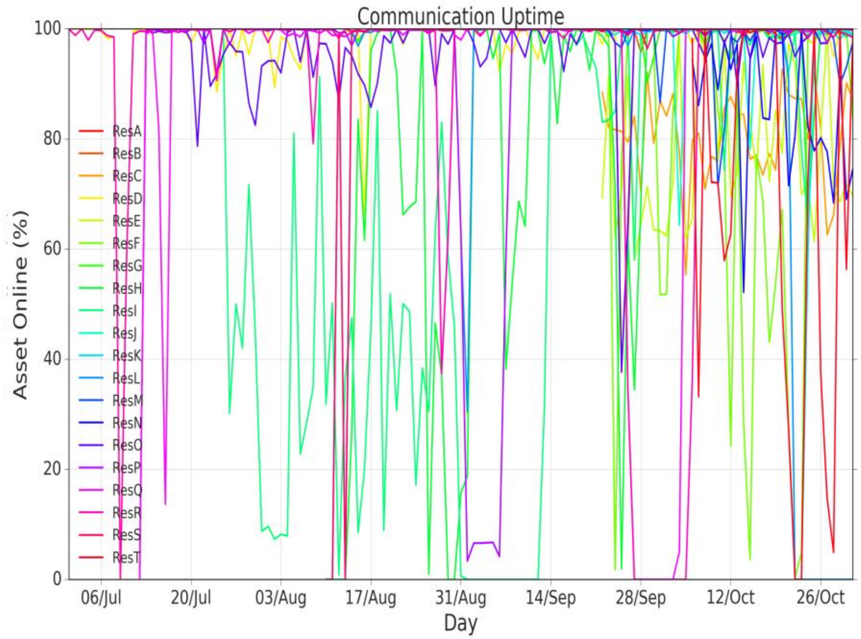
Using solar forecasting from the PG&E Weather Team, we demonstrated the ability to schedule a battery discharge to compensate for lost solar power during the August 21, 2017 eclipse.

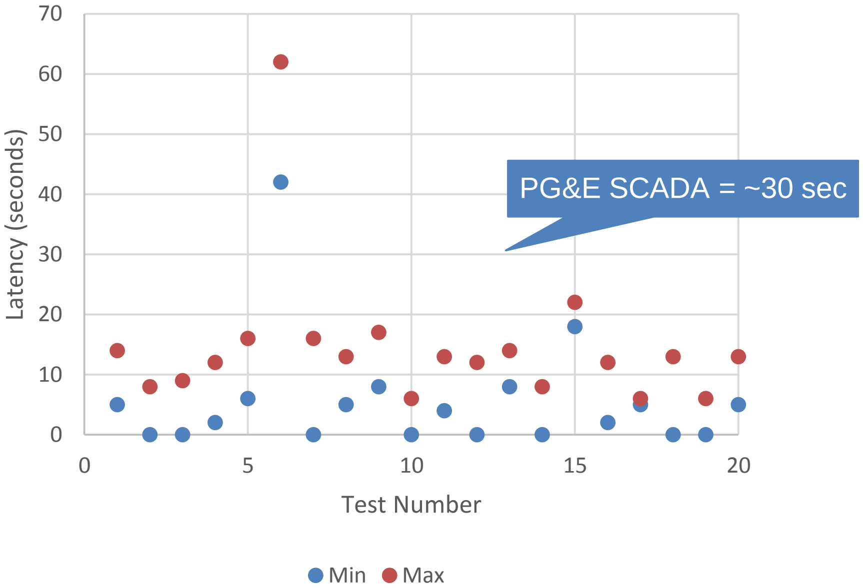
- **Weather vs Performance**
  On hot days, no change in performance for residential ESS. 1% poorer performance for commercial ESS.

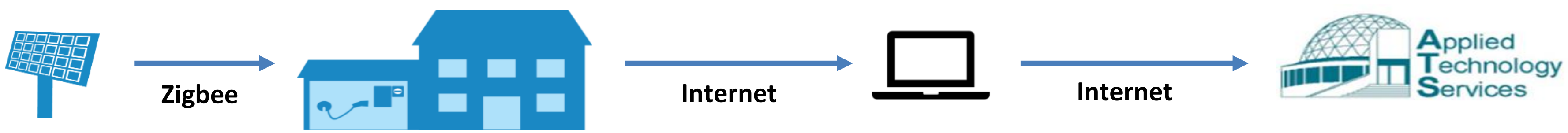
- **Load Profile**
  Commercial ESS effectively flattened customer load profile by leveraging internal algorithm. Residential ESS flattened customer load profile via scheduled charge/discharge commands.

- **Battery Charge Only on Solar**
  Demonstrated storage of all local solar generation production.

Challenges - Asset Communication







Average uptime of the 20 assets deployed ranges from 63-99%; with 16/20 maintaining an average uptime of greater than 90%.

Performance of the energy storage assets were hindered by communications challenges that should be addressed before advancing this functionality beyond the technology demonstration stage.

Challenges – Asset Communications (cont)

Asset Communications

Communication between the storage aggregator and individual storage assets was an ongoing challenge in this technology demonstration. The ability of the aggregators to reliably drop load as instructed was compromised due to frequent loss of the communications link with the storage assets.

Before pursuing wider-scale deployment of this technology demonstration, we recommend the following steps to improve communications reliability:

- Regulatory standards should specify uniform metrics for communication between utilities and BTM energy storage systems.
- Utilities and regulatory standards should specify minimum latency and communication uptime for BTM energy storage systems participating in a utility program.
- Vendors should pursue alternative communications methods to customers’ home router or cellular signals, in situations where home router or cellular signals cannot meet needed reliability requirements.
- Utilities should require minimum latency and communication uptime for BTM energy storage systems participating in a utility program.

EPIC 1.02 – Demonstrate Use of Distributed Energy Storage for Transmission and Distribution Cost Reduction

Mike Della Penna

EPIC 1.02 – Project Overview & Objectives

As part of R.10-12-007, the CPUC identified nine key barriers to the deployment of energy storage, including:

- <u>Lack of Commercial Operating Experience</u>
- <u>Lack of Definitive Operational Needs</u>
- Lack of Transparency…in Wholesale Price Signals*
- Lack of Well Defined Interconnection Processes*

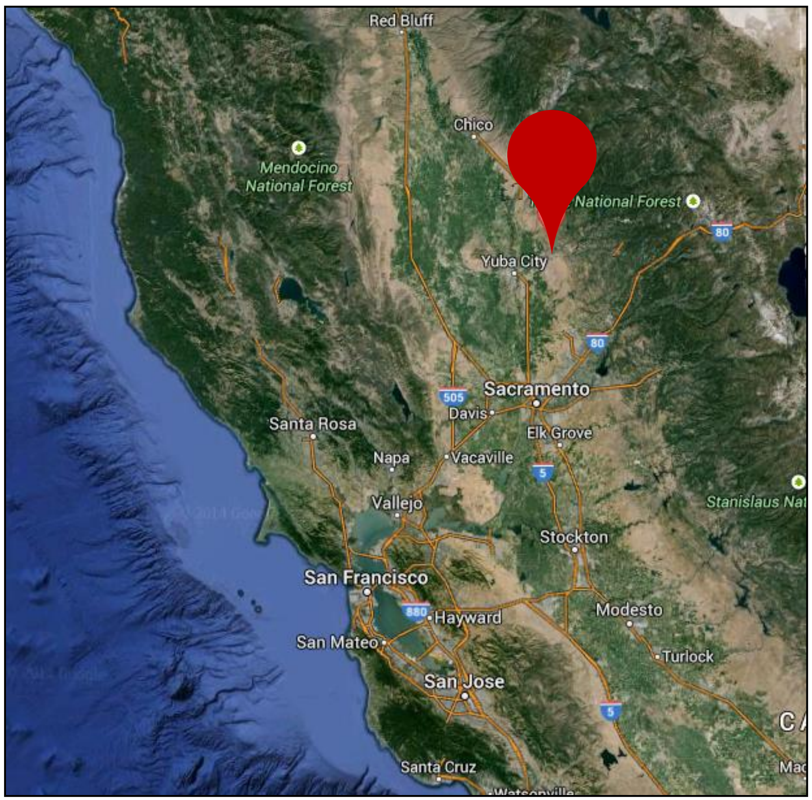
To address these barriers, EPIC 1.02 established the following project objectives:

1) <u>Demonstrate</u> the ability of a utility-operated energy storage asset to address capacity overloads on the distribution system and improve reliability;
2) <u>Evaluate</u> energy storage controls systems for deployment with this project and develop learnings to inform future controls deployment for utility operated energy storage; and
3) <u>Integrate</u> energy storage functionality with existing Distribution Operations protocols, roles and responsibilities based on use-cases deployed.

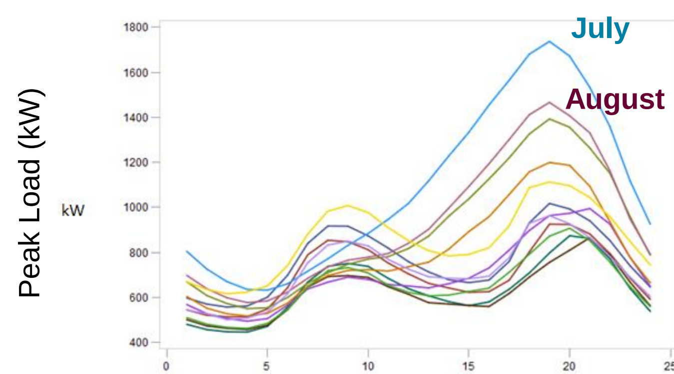
**Addressed in PG&E's EPIC Project 1.01*

Selection of Site to Meet Project Objectives

PG&E’s Browns Valley substation was selected for its alignment with the key project objective of demonstrating how large scale energy storage could be used for autonomous peak shaving to aid in a situation with a minor overload projected on a substation.



Average Daily Load Curve by Month



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Key Accomplishment: Tested energy storage system performance parameters and analyzed results

PG&E developed protocol based on industry guidelines and internal testing experiences which served as foundation for EPRI Energy Storage Test Manual

Performance Test Descriptions

Test Name	Test Description
Maximum Power/Full Duty Cycle Efficiency/Daily Efficiency	Goal: Determine whether maximum power and discharge duration performance meets minimum specifications and confirm charge duration and full duty cycle efficiency meets manufacturer's stated values
Stored Energy Capacity	Goal: Characterize general facility performance and determine usable capacity at various discharge and charge rates.
Partial Duty Cycle	Goal: Confirm partial duty cycle performance and partial duty cycle efficiency meet manufacturer's stated values.
Standby Self-Discharge	Goal: Measure system's loss of state of charge while sitting idle
Standby Energy Consumption	Goal: Measure system's energy consumption while sitting idle
Response Time, Power Factor (Real/Reactive Power), and Frequency Regulation	Goal: Measure system's time to respond to set points, characterize the system's ability to produce and consume both real and reactive power and confirm system's ability to follow a frequency regulation-like set point
Substation Bank Load Management (SCADA Control Application)	Goal: Confirm and characterize system's ability to follow SCADA input of substation bank loading and respond accordingly to shave peaks per pre-established threshold

Key Accomplishment: Tested energy storage system performance parameters and analyzed results (cont.)

Browns Valley Battery Energy Storage System key performance metric measured values aligned with guaranteed values

Metric	Description	Vendor Guaranteed Value	Actual Measured
Dmax (Discharge MW)	Maximum system discharging power	0.475	0.472*
Discharge Duration (hours)	The amount of time required to fully discharge system from 100% state of charge	4	4
Cmax (Charge MW)	Maximum system charging power	0.500	0.477*
Charge Duration (hours)	The amount of time required to fully discharge system from 100% state of charge	5.08	5.07
Full Duty Cycle Efficiency (%)	Ratio of the energy output to the grid compared to the energy consumed under various cycling scenarios	83.50%	82.62%
Partial Duty Cycle Efficiency (%)		83.50%	82.79%
Daily Efficiency (%)		77.00%	82.62%

Key Accomplishment: Autonomous peak shaving functionality built into SCADA control layer

EPIC 1.02 built upon the control backbone implemented in EPIC 1.01 to deploy autonomous substation bank load shaving functionality

PG&E SCADA

Browns Valley Substation

Browns Valley Substation Bank Electro Industries Meter

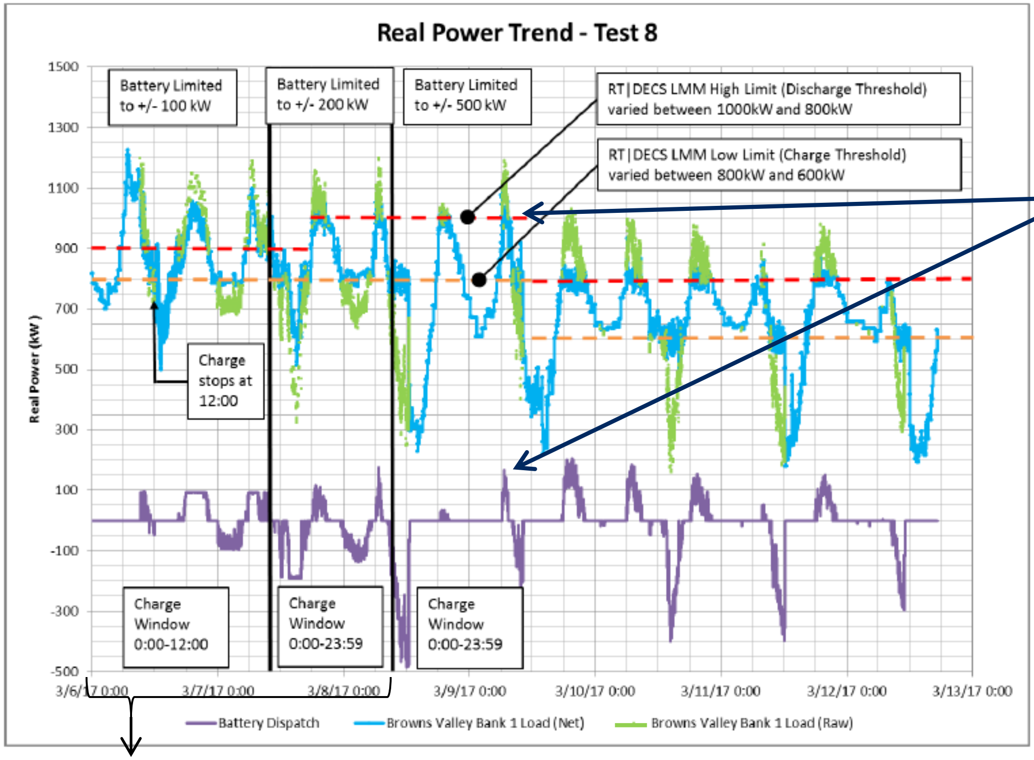
Browns Valley Energy Storage

Energy storage site master controller

Key Accomplishment: Browns Valley battery energy storage system proved capable of autonomous peak shaving

The Browns Valley Battery Energy Storage System successfully passed initial performance tests, including autonomous "bank load management" as required

Bank Load Management Mode Test Results

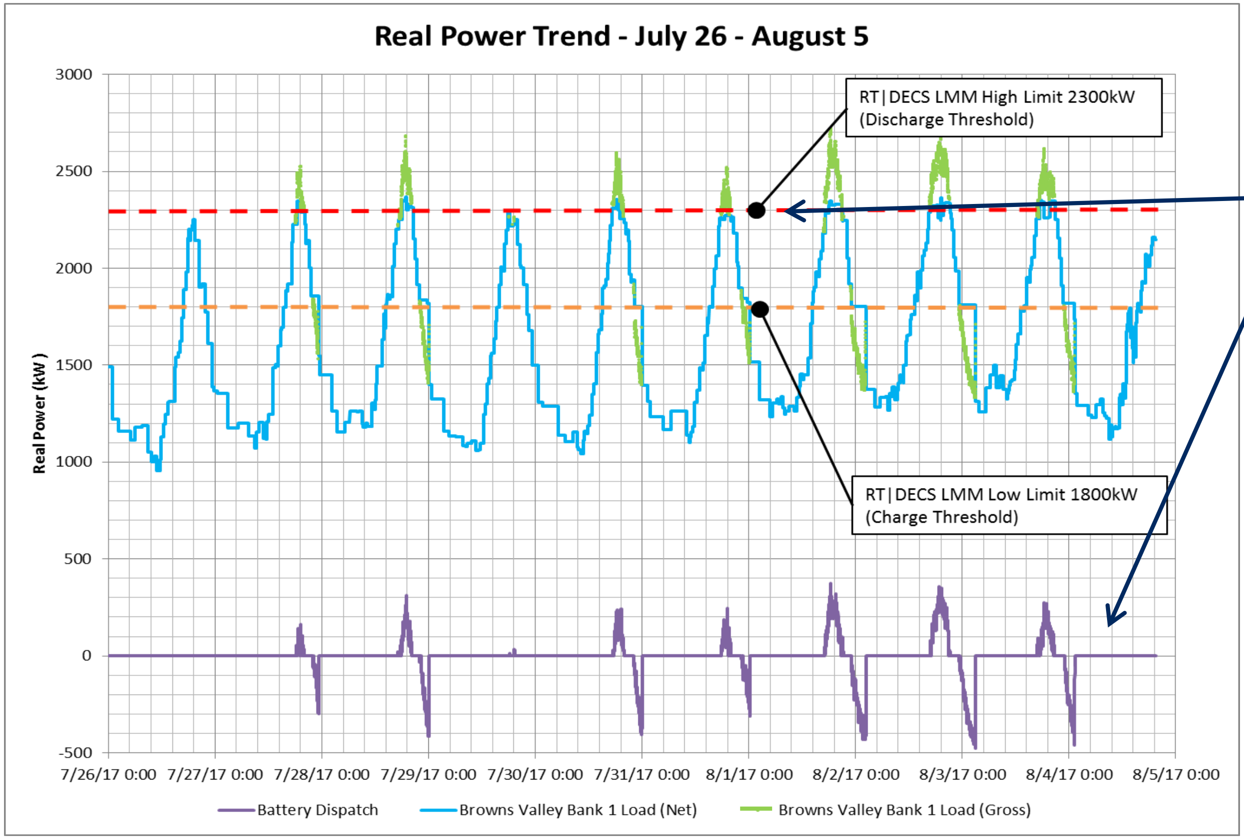


Testing period, bank load management not yet active

The net loading at the substation (blue) does not cross the set threshold (red) due to BESS dispatch (purple)

Key Accomplishment: Demonstrated during summer 2017 to keep loading below transformer threshold

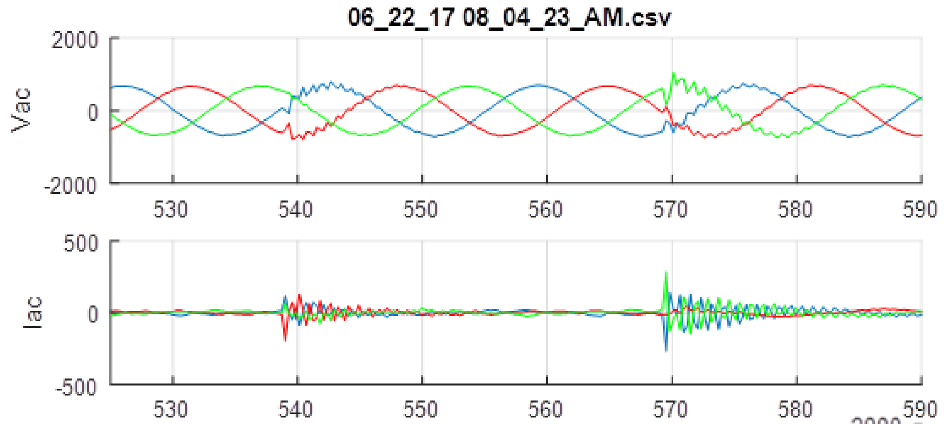
The Browns Valley Battery Energy Storage System successfully kept bank loading below 2.3MW during summer of 2017 heat wave as shown below



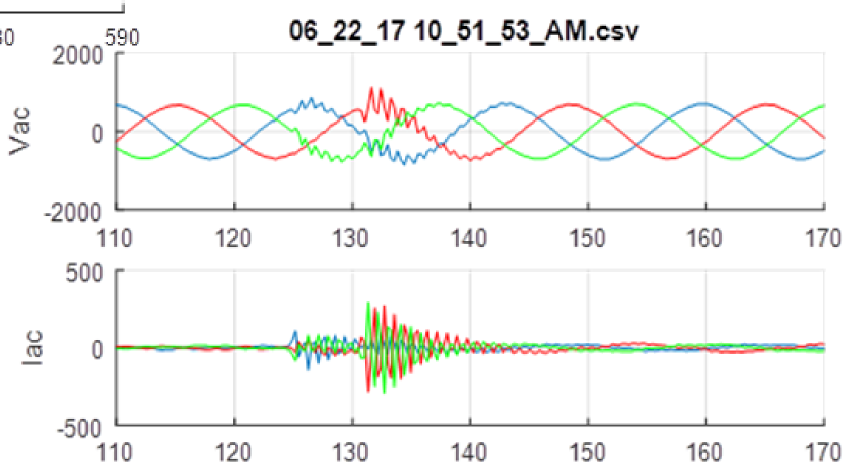
The net loading at the substation (blue) does not cross the set threshold (red) due to BESS dispatch (purple)

Key Learning: Capacitor switching interactions with Browns Valley BESS initially proved problematic until settings changes

Hot temperature triggered line capacitor bank switching which led to multiple events with inverters tripping offline – inverter settings had to be changed



Events from 6/22/17



Voltage (Vac) and current (Iac) waveforms

Key Project Takeaways

The implementation and operational learnings generated by EPIC Project 1.02 will support PG&E's future procurement of both utility-owned and utility-contracted energy storage resources and will inform state-wide policy discussions

Key insights from Browns Valley ES project implementation

- Utility-owned and controlled energy storage demonstration project can provide peak-shaving functionality
- Energy storage implementation requires significant effort that scales less than linearly with project size
- Defining requirements upfront is critical for procurement success, which directly improves future Energy Storage RFOs

Will support future procurement efforts and policy discussions

EPIC Projects Deliver Value in 2016 ESRFO

EPIC 1.01 and EPIC 1.02 learnings were used immediately in the 2016 Energy Storage RFO via Llagas energy storage project to achieve best value for customers

EPIC 1.01 – Energy Storage for Market Operations

EPIC 1.02 – Energy Storage for Distribution Operations

Llagas Energy Storage Project

Selecting …Llagas … for the preferred portfolio added a dual-use project with the unique objective of using energy storage to defer substation upgrades and with the extra value of an energy storage asset that should return CAISO energy and ancillary service market revenues to the ratepayers of PG&E. [2016 ESRFO Independent Evaluator Report]

Post-EPIC Project Plans

1. Maintain and improve the autonomous bank load management control scheme as a platform for automating the response of current and future PG&E battery storage resources

2. Investigate future demonstration applications of Browns Valley Battery Energy Storage System, such as phase balancing

3. Evaluate with other Energy Storage approaches to help shape Energy Storage strategy conversations both within California and the larger industry

Q&A